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Maize (*Zea mays* L.) yield stability dependence on crop rotation, fertilization and climatic conditions in a long-term experiment on *Haplic Chernozem*

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Abstract

Temperate regions are known to differ in climatic conditions which can considerably affect maize vegetative growth and yield. In order to determine the year-by-treatment interaction stability analysis was performed, while relative stability was determined by comparing selected treatments versus yield difference of selected cropping systems on *Haplic Chernozem* (*CHha*). Analysis of variance for maize grain indicated differences between treatments, while significantly higher yield was observed at a fertilized 3-year (6854 kg ha^{-1}) and 2-year rotation (6721 kg ha^{-1}). Stability analysis ($P < 0.01$) showed significant response of maize yield to the agroecological mean yield when linear regression was applied. The effect of crop rotation on maize yield was inversely proportional to the ratio of the maize in the sequence. Relative stability showed that the higher yield sensitivity to favourable climatic conditions would be with maize monoculture ($r = 0.76$), and unfertilized rotations showed a decreasing yield trend when mean agroecological yield was increasing ($P < 0.05$). When comparing simulated root mean square error (RMSE) of yield stability, the fertilized 2-year rotation and the monoculture fit into $\text{RMSE}_{95\%}$ confidence interval ($P < 0.05$). The results demonstrated that the stability analysis can help in selection of maize technology and interpretation of environment × treatment interaction observed in a long-term experiment.

Key words: environment, yield, yield stability, *Zea mays*.

Introduction

Long-term experiments represent a systems approach in crop production research, aiming to facilitate and efficiently utilize the available natural resources. However, the practice of crop rotation in long-term experiments has often been difficult to explain due to "rotation effects" which had empirical rather than practical verification that confused scientists (Karlen et al., 1994). The analysis of crop rotation data is complicated due to yearly replications, cycles and crop order, correlation errors and changes in cropping technology (Berzsenyi et al., 2000). Most authors point out that the climatic conditions of a growing-season remain the critical factor affecting yield and yield temporal variability (Hu, Buyanovsky, 2003). Likewise, years prove to be significantly different, and with the anticipated inconsistency of treatments, this could bias the year-by-treatment interaction. With such changes over time it is difficult to properly evaluate cropping systems due to the complexity of the factors influencing yield formation. Some authors used regression analysis to determine yield stability in order to interpret stability analysis in crop production (Raun et al., 1993). The concept of stability implies that there is a random, unpredictable element in performance of a cropping system. The larger this random factor is the smaller is the stability of a system. A common approach to stability analysis is to correlate the performance of the system with the environmental mean calculated as the mean of all treatments in an environment. Regression techniques used to develop stability parameters are based on a linear slope and a deviation from this slope. Systems where the regression has a relatively large slope show an above-average response to improved environmental conditions. Non-independence of variables used in the regression as well as potential interdependence of the different linear equations to be compared become a critical consideration when one uses stability analyses to separate treatment response as a function of the environmental mean. Mead et al. (1986) explain that yield stability over time involves at least three distinct components: i) the relationship of yield with the local environment, ii) the average yield level and iii) the variability of yield. Understanding the temporal variability in crop yields has implications on the sustainable maize production, particularly since greater fluxes in crop yields are projected with global climate change. With projected rapid changes in the soil-plant-atmosphere system, mainly due to CO_2 increase, yield variability could expand in the future (Birkás, 2009). However, the regional climate responses to the doubling of the atmospheric CO_2 concentration are significantly different (Watson et al., 1998). It is considered that, in general, the stability of maize production under conditions of elevated CO_2 depends mainly on the better use of water (Brown, 1999). According to Pejić et al. (2011), Pannonian Basin is a typical temperate region where water requirements of maize are rarely met through precipitation received during the growing season. A recent study showed that the mean temperatures and precipitation and their variability have been increasing (Lalić et al., 2011), which could have a direct and indirect impact on yield formation. Therefore, maize production must be based on a stable system that changes least in response to changes of the environment. The objectives of this paper are to evaluate the long-term effects of different cropping systems on yield and yield stability of maize in relation to the temporal changes of the climatic conditions in the temperate region of the Pannonian Basin.

Materials and methods

The present study was performed in a long-term crop rotation trial carried out at the Rimski Šančevi Experimental Field of the Institute of Field and Vegetable Crops in Novi Sad (45°19′ N, 19°50′ E), Serbia – the South-Eastern segment of the Pannonian Basin. The trial began in the period 1946–1947 (I phase) and it was modified in 1969–1970 (II phase) when fertilized treatments, described in our study, were introduced. Fertilized plots (90 × 30 m) and unfertilized plots (44 × 23 m) were arranged as a single crop rotation where all crops of the same rotation were grown each year according to the experimental design. Replication across treatments and effects of a year were considered a random effect and cropping systems were considered a fixed effect. The current fertilization scheme has not been changed since 1987. Our investigation was performed on *Haplic Chernozem* (*CHha*) according to the IUSS Working Group WRB (2006). Soil chemical analysis of the investigated plots underwent considerable changes in the decades following the experimental set-up, however, during the observation period in this study, they were not altered (Šeremešić et al., 2008). The data on climatic characteristics indicate semiarid conditions with an uneven precipitation distribution over the vegetation season (Table 1). The critical period for maize yield formation is considered to be in June, July and August when precipitation deficit occurred in most years. Therefore, we assume that climatic conditions could have a prevailing effect on maize yield formation.

Table 1. Average precipitation and temperatures at the Experimental Station Rimski Šančevi, Novi Sad, Serbia

	Period	Months												Average
		01	02	03	04	05	06	07	08	09	10	11	12	
Temperature °C	1970–2010	0.2	1.9	6.5	11.5	17.0	20.0	21.6	21.2	16.7	11.4	5.8	1.5	11.3
	1991–2010	0.5	2	6.6	12.0	17.4	20.5	22.2	21.9	16.6	11.7	6.5	1.2	11.6
Precipitation mm	1970–2010	36.5	31.4	38.9	49.4	59.6	88.5	65.6	63.1	47.6	52.2	52.0	43.1	628.0
	1991–2010	38.5	30.8	34.7	48.5	58.5	91.7	77.4	66.4	60.5	61.1	61.0	52.5	681.5

The study treatments were the following: a fertilized monoculture (100% maize) – MO, a fertilized 2-year crop rotation (50% maize and 50% winter wheat) – D2, a fertilized 3-year crop rotation (33.33% maize, 33.33% soybean and 33.33% winter wheat) – D3, a fertilized 4-year crop rotation (25% maize, 50% winter wheat and 25% field peas) – D4, a fertilized 12-year crop rotation (33.33% maize, 33.33% winter wheat, 16.16% soybean and 16.16% sugar beet) – D12, the unfertilized 2-year rotation (50% maize and 50% winter wheat) – N2, and the unfertilized 3-year rotation (33.33% maize, 33.33% soybean and 33.33% winter wheat) – N3. The fertilized treatments included mineral nitrogen (N) fertilizers at 120 kg ha^{-1} rate for maize (50 kg ha^{-1} in autumn and 70 kg ha^{-1} in spring). Phosphorus (P) and potassium (K) fertilization was based on soil analyses and applied in autumn. The unfertilized 2-year rotation (N2) and 3-year rotation (N3) have not received any fertilization since 1946–1947, and crop residue incorporation with ploughing started in 1986–1987. Maize growing was based on conventional tillage including mouldboard ploughing and seed bed preparation with a germinator manufactured by Kongskilde. Sowing took place in April at a seeding rate of 17 kg ha^{-1}, and a distance between and in rows: 70 × 25 (57.142 plants per ha). Weed control in maize was based on Dual Gold ® 960 EC (S-metolahlor (960 g l^{-1}) dose 1.4 l ha^{-1} and Lumax 537.5 SE (375 g l^{-1} S-metolahlor + 125 g l^{-1} terbutilazin + 37.5 g l^{-1} mezotrion) with dose 3.5–4 l ha^{-1} and row-crop cultivator was used each year. Control of *Sorghum halepense* (L.) Pers and other grass weeds was conducted with Motivell 1–1.2 l ha^{-1} (nicosulfuron) or Tarot 25-WG 50–60 g ha^{-1} (rimsulfuron). During the 20-year observation period (1991–2010), the leading maize hybrid NSSC 640 was grown. Grain yields were calculated as an average of four replicates every year and were adjusted to 13% moisture content for maize. In order to explain the changes in yield, stability analysis was used. This implies linear regression of the treatments yield on the location/year environmental mean yield (average yield of all treatments in a given year). Linear regression analysis was carried out without the use of data transformation. The agroecological mean (AM) was calculated as an average yield of all study treatments for each year (1991–2010). Relative stability was determined by studying the joint distribution of data pairs (the means for treatment A and B in a given year) and by comparing slopes and the regression line when the average yield of the pair $(A+B)/2$ is regressed on the yield difference between two treatments $(A-B)$. When the slope is close to zero, this indicates that the two treatments change similarly and are equally stable. A positive slope indicates that B is more stable than A since variability of A is greater. When the slope has a strongly negative direction, this suggests that A is more stable than B (Raun et al., 1993).

According to Loague and Green (1991), the total difference between the simulated (the agroecological mean) and the measured values was calculated as the root mean square error (RMSE):

$$RMSE = \frac{100}{\overline{O}}\sqrt{\sum_{n=1}^{n}(P_i - O_i)^2 / n}\,.$$

The statistical significance of RMSE was determined by comparing it to the value obtained assuming a deviation corresponds to 95% confidence interval of the measurements:

$$RMSE = \frac{100}{\overline{O}}\sqrt{\sum\nolimits_{I=1}(t_{(n-2)95\%} \times S_0(i))^2 / n},$$

where $t_{(n-2)95\%}$ is Student's t distribution with n-2 degrees of freedom and a two-tailed p-value of 0.05. Analysis of variance was used to separate the treatment means when there was a significant difference at the $P < 0.01$ and $P < 0.05$ level (Mead et al., 1993).

Results and discussion

In the combined analysis of variance over years the effects of crop sequences containing various proportions of maize showed significant F-test ($P < 0.01$) for cropping systems and years, since the treatments means and the year for the period 1991–2010 were significantly different (Lente, Pepó, 2009). The design structure employed does not differentiate year-by-treatment interaction since this source of variation is represented with error (Table 2). The cropping system accounts for 50.84% variation of yield; the year accounts for 37.08%, whereas the remaining 12.06% variation of yield derives from residual influences. Although the cropping systems showed significant influence on yield formation, the combined analysis of variance did not indicate long-term tendencies.

Table 2. Two-way analysis of variance for maize grain yield (1991–2010)

Source of variation	d.f.	s.s.	s.s.%	m.s.	*F*	*P*
Cropping system	6	421300322.	50.84	70216720.	80.05**	<0.01
Year	19	307393366.	37.08	16178598.	18.44**	<0.01
Error	114	100001010.	12.06	877202.		
Total	139	828694698.	100	5961832.		

d.f. – degrees of freedom, s.s. – total sum of squares, s.s.% – sum of squares relative to total sum, m.s. – mean squares; ** – significant at $P < 0.01$ level

The analysis of the 20-year data showed that unfertilized rotation had significantly lower yield compared with the fertilized treatments (Table 3). Among fertilized rotation, MO demonstrated significant yield reduction, and higher yields were obtained with D3 (6854 kg ha^{-1}) and D2 (6721 kg ha^{-1}), however, with no statistical difference compared with D12 ($P < 0.05$). Lower yields in MO are mainly observed after a dry winter, summer droughts, and in years with an increased weed pressure. The yield-increasing effect of rotation on maize yield was inversely proportional to the ratio of maize in the sequence (Pepó, 2009). The obtained results indicated significant differences between the observed crop rotations in soil moisture utilisation (Table 3). The fertilized MO and D12 had the largest standard deviation, because a preceding crop had influenced maize development. In addition, temperatures in both the critical period and the vegetation period had significantly affected yield formation ($P < 0.05$). The unfertilized rotations were least affected by the changes in climatic conditions since they had lower yield and small variation. According to previous studies of the same experimental fields, the fertilized rotation, particularly MO, showed a negative correlation and yield decrease when the precipitation sum exceeded 250 mm from June to August (Šeremešić, Milošev, 2006). The analysis of the effect of average temperature (June, July and August) on maize yield showed that high temperature induced a significant negative reaction on all crop rotation and decline of the yield. The temperature in the critical period of vegetation >18°C had negative effects on plants, interacting with other vegetation factors, controlling duration of growth periods, photosynthesis and indirectly plant drought reaction, availability of plant nutrients, etc.

Table 3. Average maize yield and its correlation with temperature and precipitation for the period 1991–2010

Cropping system	Yield kg ha^{-1}	±SD	±SE	Correlation (*r*)			
				Critical period		Vegetation period	
				t	P	t	P
MO	5058 b	2064	475.0	−0.73*	0.38	−0.69*	0.34
D2	6721 a	1943	404.8	−0.73*	0.50*	−0.60*	0.40
D3	6854 a	1832	393.5	−0.79**	0.65*	−0.70*	0.53*
N2	2267 c	1374	209.5	−0.53*	0.28	−0.55	0.26
N3	3033 c	1503	235.3	−0.57*	0.38	−0.65*	0.43
D4	5882 b	1937	380.6	−0.74*	0.67*	−0.74*	0.53*
D12	6108 ab	2074	454.2	−0.69*	0.23	−0.58*	0.20

Note. a-c – numbers in collumn followed by the same letters do not differ significantly at the $P < 0.05$ level; *r – significant at $P < 0.05$, **r – significant at $P < 0.01$; ±SD – standard deviation, ±SE – standard error; t – temperature, P – precipitation.

The regression analysis shows that the stability of various crop sequences differs. Generally, when linear regression was applied, r coefficient for all cropping systems showed small variation and significantly corresponded to the AM (Table 4). The small dissimilarity among regression coefficients can be attributed to the variation between the intercepts, and ability in utilization of environmental resources. The higher value of r was found with D2 ($r = 0.94$) at $P < 0.01$ and lower in N2 ($r = 0.78$) at $P < 0.01$. The investigated cropping systems showed high response of applied linear regression and MO showed higher yield increase with each unit of AM increase ($b = 1.44$). By accepting the hypothesis that the AM is a modelled value, the root mean square error RMSE could be used for testing significant total error and verifying the "goodness of fit" between the observed and modelled yield levels. Table 4 shows that the RMSE for maize yield increases with maize proportion in rotation. An RMSE value less than the root mean square error 95% confidence interval ($RMSE_{95\%}$) indicates that the simulated values fall within the 95% confidence gap of the measurements. Significant total error was found when maize was cropped in MO and D2 which confirmed yield dependence of those cropping systems on the mean agroecological yield change ($P < 0.05$). Although maize MO and D2 rotation could produce higher yield in the long-term period, they could not be recommended for maize growing because of significant interdependence on environmental conditions. Furthermore, growing maize in wide rotation (D4 and D12) revealed that the effects of a preceding crop could be modified in relation to the year climatic conditions.

Table 4. Regression analysis of yield stability in maize cropping

Cropping system	Intercept		Slope		CV	*p*	*r*	RMSE	
	intercept	SE of intercept	slope	SE of slope				model (AM)	95% confidence limit
MO	−0.78	0.73	1.44	0.13	40.79	0.29	0.87**	20.08	43.95*
D2	0.77	0.47	1.16	0.08	28.86	0.11	0.94**	26.61	33.21*
D3	1.33	0.49	1.08	0.09	26.71	0.01	0.92**	27.42	10.68
N2	−1.21	0.62	0.68	0.11	60.61	0.06	0.78**	78.86	29.61
N3	−0.91	0.63	0.77	0.11	49.50	0.16	0.80**	132.21	37.14
D4	0.44	0.70	1.06	0.13	32.82	0.53	0.86**	21.02	12.45
D12	0.31	0.76	1.13	0.14	33.93	0.68	0.86**	23.91	12.22

CV – coefficient of variation, *p* – *p*-value, *r* – correlation coefficient; AM – agroecological mean; ** – significant at $P < 0.01$, * – significant at $P < 0.05$

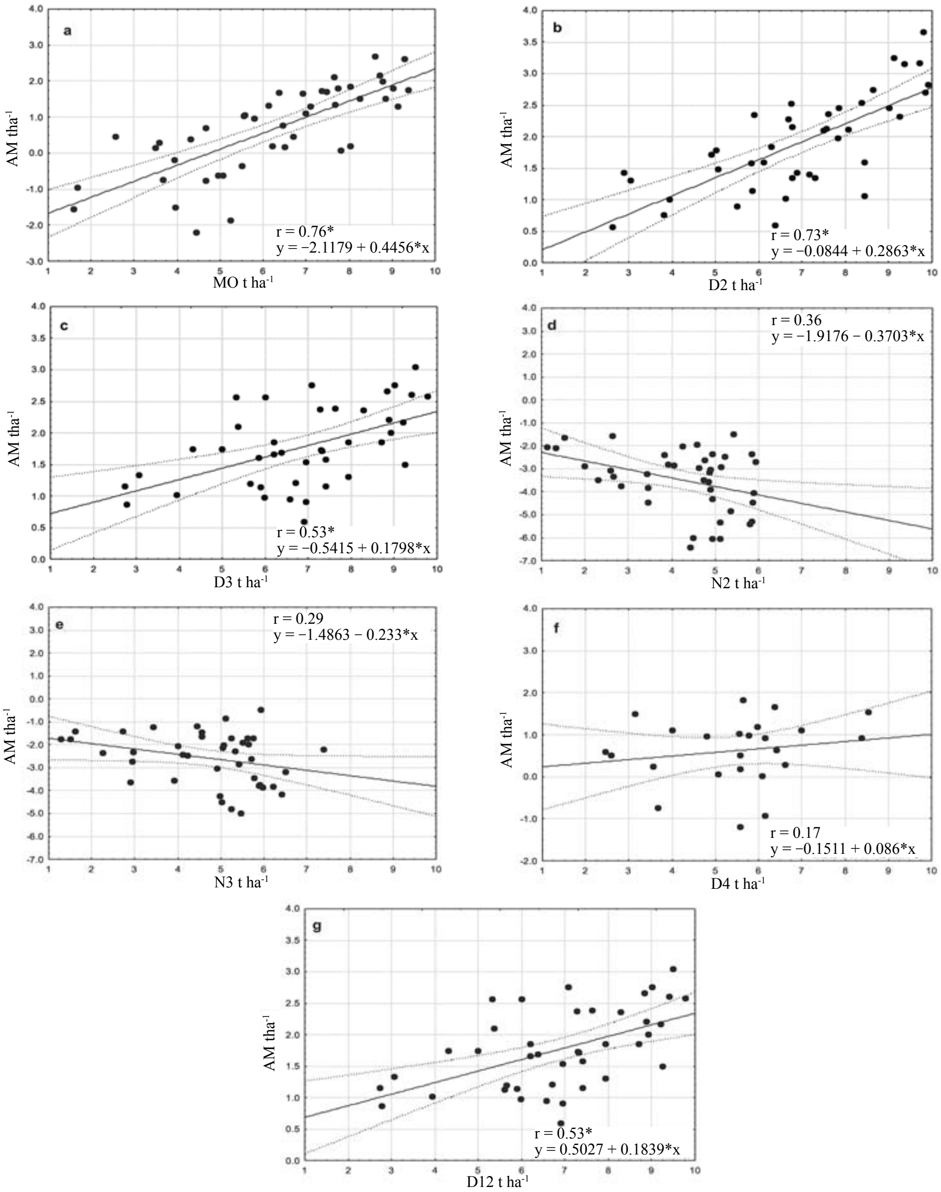

Figure. Relative yield stability of a) maize monoculture (MO), b) fertilized 2-year rotation (D2), c) fertilized 3-year rotation (D3), d) unfertilized 2-year rotation (N2), e) unfertilized 3-year rotation (N3), f) fertilized 4-year rotation (D4), g) fertilized 12-year rotation (D12) compared with the agroecological mean (AM); * – significant at $P < 0.05$

A significant linear trend was found when plotting maize yield of contrasting cropping systems (Table 4). To determine whether the slope will not equal zero hypothesis was tested H_0: ß1 = 0. For the normal stability analysis null hypothesis will be rejected if *p*-value is less than the significance level ($p < 0.01$) and the slope will differ from zero. The unfertilized rotation showed the weakest correlation indicating a lack of environmental interrelation in favour of an independent system driven by significant constrains regarding soil fertility. This combined regression analysis revealed the importance of the year, rotation, fertilization and climate. Generally, MO demonstrated a satisfactory level of adaptation to environment although significant yield variation was observed. Values of the yield stability have shown that, in the majority of cases, the cropping systems with the highest grain yield were not the most stable ones (Delić et al., 2009).

The main difference among stability analysis and relative stability is elimination of possible interdependence between regressions. Therefore, observing slopes significantly different from zero implies that the environment-specific treatment response did exist. The relative stability had much lower *r* compared with the normal stability analysis (Fig.). This combined regression analysis revealed the importance of the reaction of the cropping systems to the change in environment in describing the maize yield change of different cropping systems. The relationship between MO and AM ($r = 0.76$) indicates a high and statistically significant correlation of the monoculture with the environmental average yield ($P < 0.05$).

Under favourable conditions for maize growing, the monoculture reacted with increased yields and a significant relationship with AM ($r = 0.76$) ($P < 0.05$). Those conditions may occur in the years with sufficient precipitation and an appropriate rainfall schedule. Wilhelm and Wortmann (2004) confirmed that, under rain-fed conditions in south-eastern Nebraska, the maize yield increased with less spring and more summer rainfall. Fertilized D2, D3 and D12 respond positively ($r = 0.73$, $r = 0.52$ and $r = 0.53$, respectively) to occurrence of favourable agricultural conditions with high regression coefficient ($P < 0.05$). The relative yield stability of D4 is positive, but correlation ($r = 0.17$) does not explain the statistical relationship between changes in maize yield in D4 and a change in AM yield. Cultivation of maize in a 4-year crop rotation with two years of winter wheat resulted with expansion of weeds, therefore less yield potential and lower stability was observed. Although maize can effectively control weeds after reaching the maturity stage, in the early stages of growth weed suppression in maize can be considered critical for successful plant development (Gaile, 2012). Relative instability of D4 is confirmed by a lower maize yield on this plot compared to D2, D3 and D12 and with the higher variation of grain yield.

The gradual increase in regression coefficient that was obtained in D3, D2 and MO, respectively, indicates that the increasing proportion of maize in rotation resulted with higher dependence on environmental conditions. Grover et al. (2009) also found that the rotation effects appeared to vary by years and, in high-yielding years, the monoculture may produce similar maize yields compared with the rotation cropping. At the same time, a relatively high yield of maize in D2, which is not statistically different from D3, is a result of the same preceding crop in both D2 and D3. The unfertilized plots, which were established in 1946–1947, showed the opposite trend with increasing the AM yield. Lower yield of the unfertilized treatments primarily occurs due to intensive weed growth which suppresses intensive crop development in the early stages of vegetation, later causing lagging and shortening of grain filling stage. The relationship between yield at the unfertilized rotation (N2 and N3) related with the AM is explained with a low correlation $r = 0.36$ and $r = 0.29$, respectively ($P < 0.05$).

Conclusions

1. The evaluation of the cropping systems in a long-term experiment showed higher yield in a fertilized 3-year rotation (6854 kg ha^{-1}) and a 2-year rotation (6721 kg ha^{-1}) in comparison with other cropping systems. Nevertheless, a fertilized 3-year rotation showed higher yield dependence on climatic conditions in a critical period for precipitation $r = 0.65$ ($P < 0.05$) and temperature $r = -0.79$ ($P < 0.01$) and for the vegetation period (precipitation $r = 0.53$ and temperature $r = -0.70$; $P < 0.05$), which could be attributed to high potential for utilization of environmental resources.

2. By comparing simulated RMSE and $RMSE_{95}$, it was found that the monoculture and a 2-year rotation best fit the modelled yield level ($P < 0.05$), although all cropping systems had a significant correlation to the agroecological mean yield ($P < 0.01$).

3. Stability analysis showed good adaptability to the environment of all the investigated cropping systems. However, when relative stability was applied it was found that the maize monoculture ($r = 0.76$) and a 2-year rotation ($r = 0.73$) were the most dependent on utilizing environmental resources ($P < 0.05$). Based on the relative yield stability, high yield and yield stability are not mutually exclusive. The unfertilized rotation had a decreasing yield trend with increasing the agroecological mean yield.

4. The results of this study indicate that in temperate regions significant yield reduction of maize comes from increased temperature and moisture deficit despite the fact that modern technology was applied. As the issue of sustainability becomes increasingly important, stability analyses and relative stability may help in understanding the yield as a result of environmental processes.

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Paprastojo kukurūzo (*Zea mays* L.) derliaus stabilumo priklausomumas nuo sėjomainos, tręšimo ir klimato sąlygų juodžemyje įrengtame ilgalaikiame eksperimente

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Santrauka

Vidutinio klimato regionai skiriasi klimato sąlygomis, kurios gali smarkiai veikti kukurūzų augimą ir derlių. Siekiant nustatyti metų ir variantų sąveiką, buvo atlikta stabilumo analizė, o santykinis stabilumas nustatytas lyginant pasirinktų variantų derliaus skirtumus įvairiose žemdirbystės sistemose paprastajame juodžemyje (*Haplic Chernozem*, *CHha*). Kukurūzų grūdų dispersinė analizė parodė skirtumus tarp variantų: esmingai didesnis derlius buvo gautas tręšiant trimetėje (6854 kg ha^{-1}) ir dvimetėje (6721 kg ha^{-1}) sėjomainų rotacijose. Taikant tiesinę regresiją, stabilumo analizė ($P < 0,01$) parodė esminį kukurūzų derliaus ryšį su vidutiniu agroekologiniu derliumi. Sėjomainos įtaka kukurūzų derliui buvo atvirkščiai proporcinga kukurūzų santykiui sėjomainos grandyje. Santykinis stabilumas parodė, kad didesnis derliaus atsakas į palankias klimato sąlygas būtų kukurūzų monokultūros ($r = 0,76$), o netręšiant sėjomainose nustatyta derliaus mažėjimo tendencija, kai vidutinis agroekologinis derlius didėjo ($P < 0,05$). Palyginus sumodeliuotą derliaus stabilumo vidutinę kvadratinio vidurkio paklaidą (VKVP), tręšiant dvimetė sėjomaina atitinko $VKVP_{95\%}$ tikimybės intervalą ($P < 0,05$). Tyrimo rezultatai parodė, kad stabilumo analizė gali padėti pasirenkant ilgalaikio bandymo kukurūzų auginimo technologiją ir interpretuojant aplinkos bei variantų sąveiką.

Reikšminiai žodžiai: aplinka, derliaus stabilumas, derlius, *Zea mays*.